

Precision top quark physics at a future linear e^+e^- collider : top quark couplings

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on behalf of the LC community

With special thanks to:

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I Garcia, E. Ros, P. Ruiz Femenia (IFIC Valencia)



Outline²⁰⁰⁹

- Future e⁺e⁻ colliders
- Detectors
- Top quark couplings

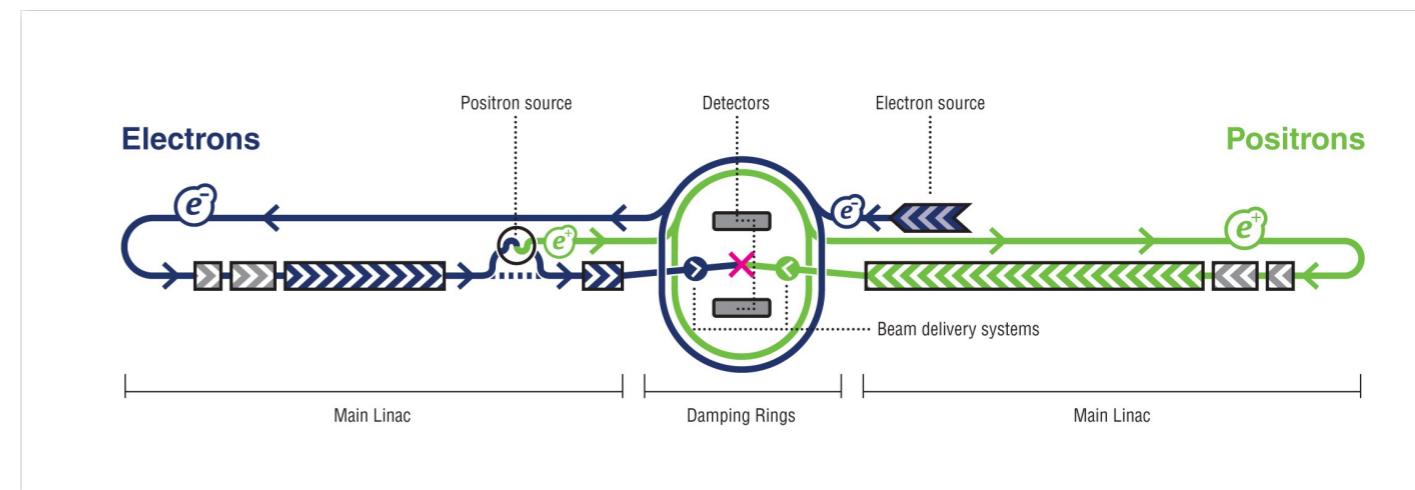
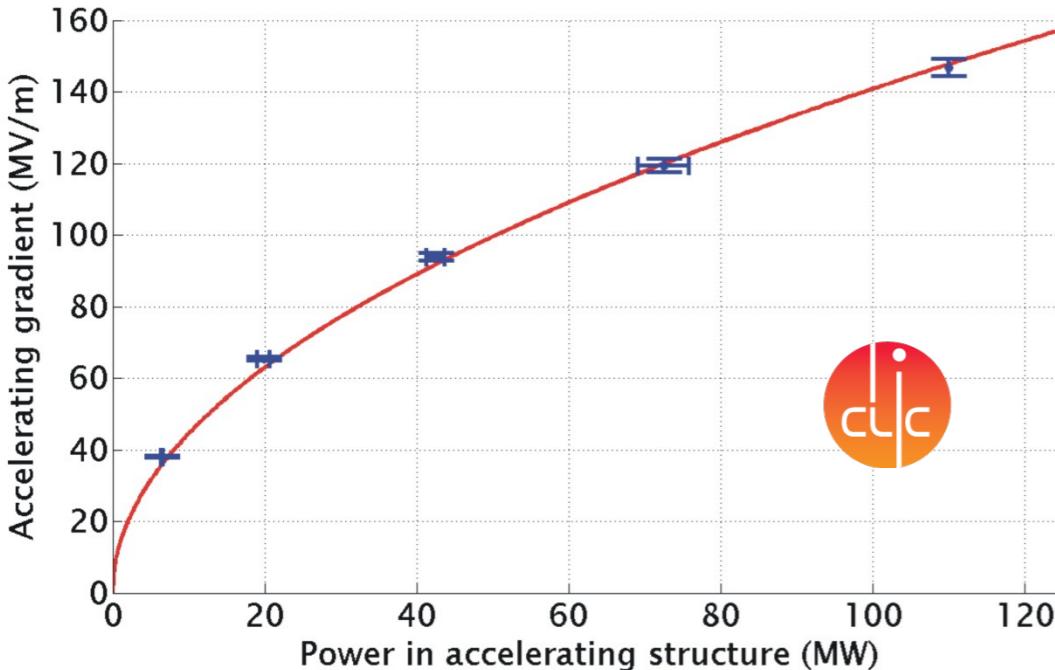


Reference documents prepared by the LC community:

- Tesla TDR (2001) [part III](#) on physics
- 2004 [Report](#) on the complementarity of LC and LHC
- CLIC [physics report](#)
- ILC Reference Design Report (2007): [physics](#) and [detectors](#)
- Letter Of Intent of the ILC experiments (2009) [SiD](#) and [ILD](#)
- Conceptual Design Report (2012) of the [CLIC detectors](#)
- Soon: Detailed Baseline Design for the ILC experiments

Future e⁺e⁻ colliders

- Superconducting RF cavities are in the industrialization phase and routinely reach gradients well over 30 MV/m. **ILC is shovel-ready.**
- Still higher gradient (~ 100 MV/m) can be achieved using drive beam concept. **CLIC can open up the multi-TeV regime.**



R&D around the globe
Non-exhaustive list of test facilities:
ATF@KEK, nm size, low emittance beams
CESR/IT@Cornell (electron cloud)
CTF3@CERN, drive beam
XFEL@DESY, cavities

LC technology exists for a low-energy machine ($\sqrt{s} \sim 250\text{-}500$ GeV)
Note that CLIC envisages a low-energy stage. R&D is ongoing for $\sqrt{s} \sim 1\text{-}3$ TeV

Top@LC: Theory input

QCD corrections

to $e^+e^- \rightarrow tt + X$,

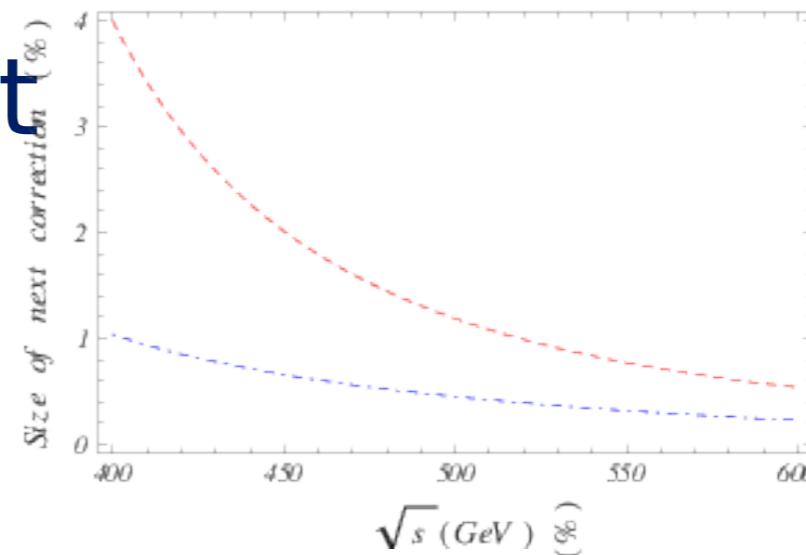
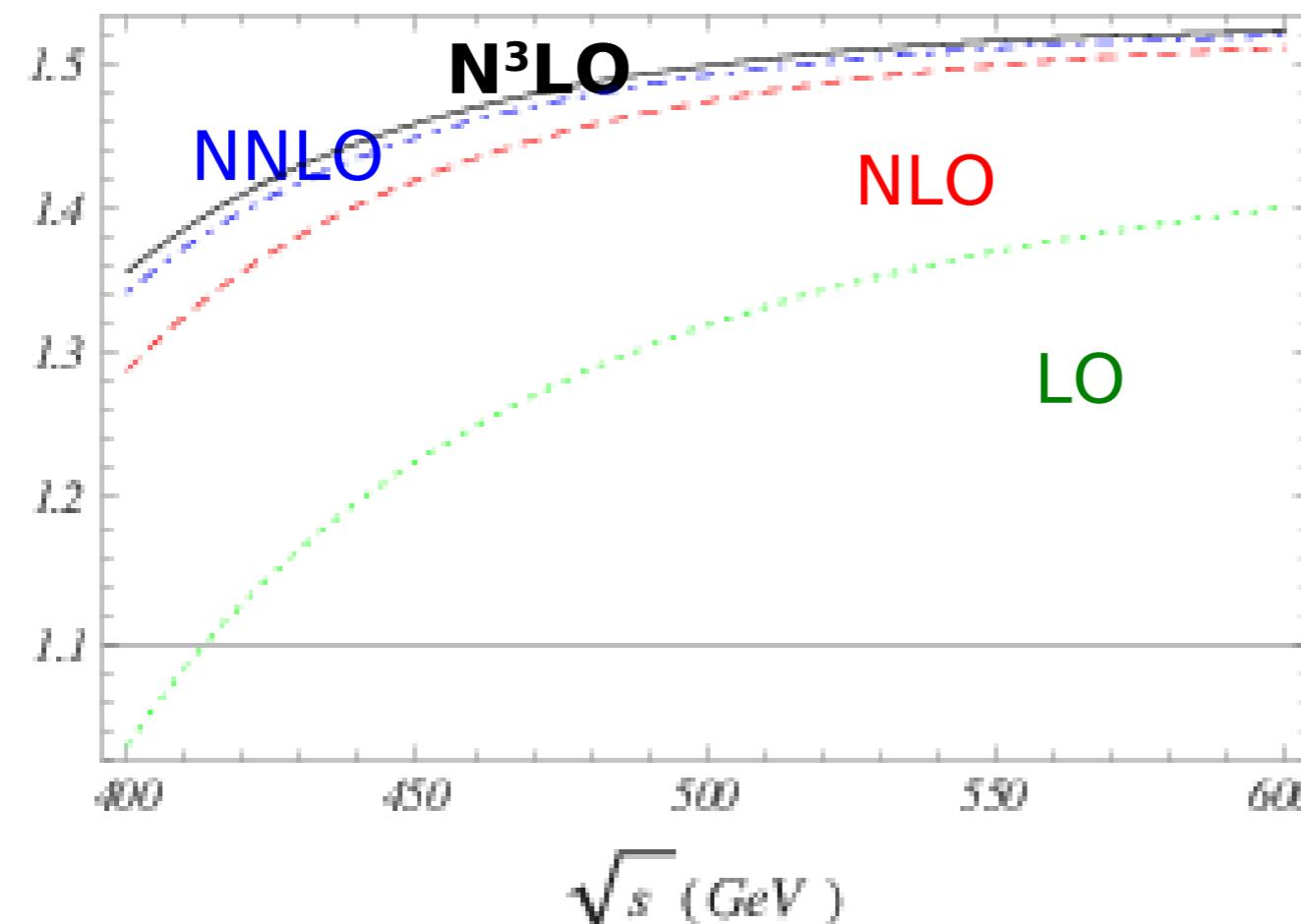
known up to $O(\alpha_s^3)$ (3-loops)

Kiyo, Maier, Maierhöfer, P. Marquard, arXiv:0907.2120

Hoang, Mateu, Zebarjad, Nucl. Phys. B 813 (2009) 349-369

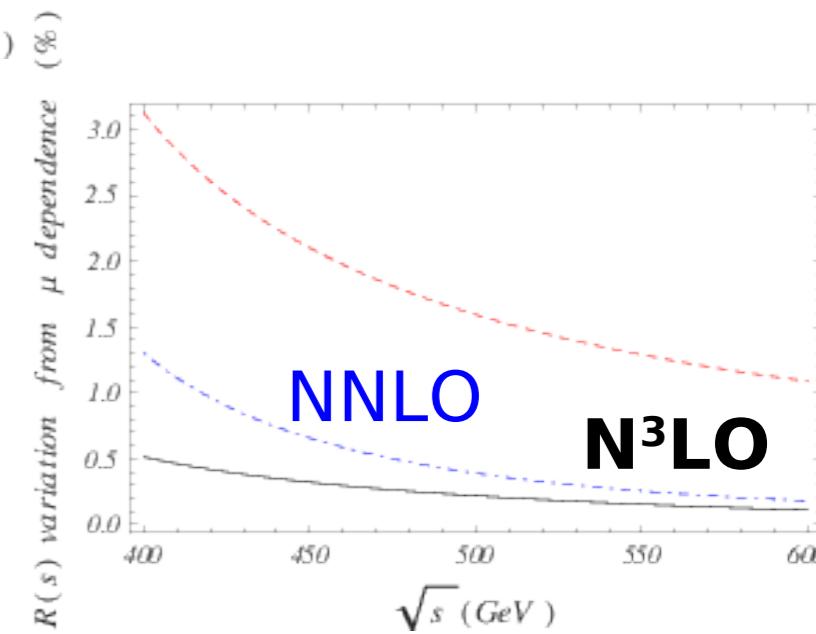
Bernreuther, Bonciani et al., hep-ph/0604031

$R(s) = \text{cross-section normalized}$



Scale dependence

NLO: ~1.5 %
NNLO: ~0.4 %
N³LO: ~0.3 %



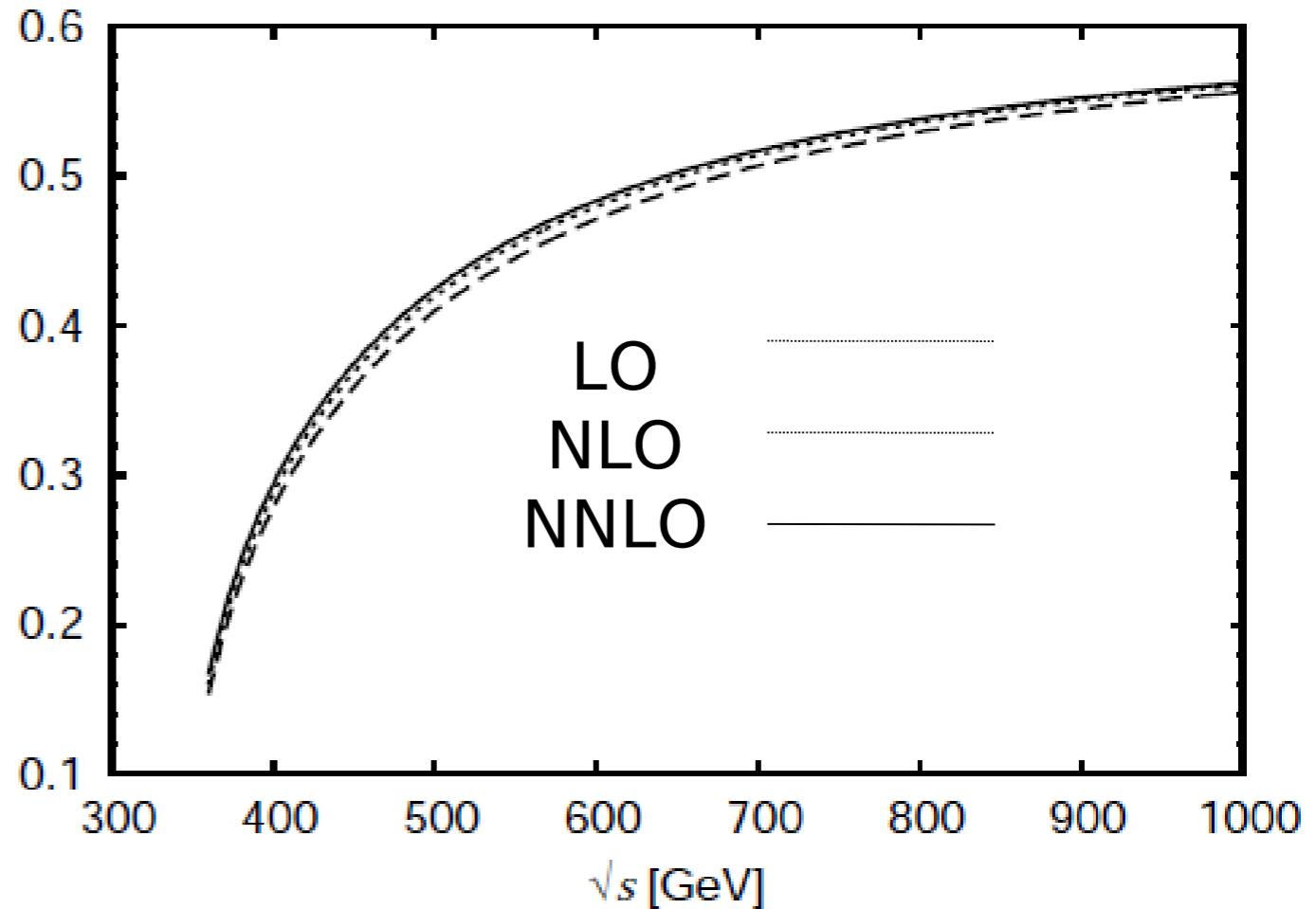
Current state-of-the-art calculations yields inclusive x-sec with an uncertainty at the 3 per mil level



Top@LC: Theory input

What about A_{FB} ?

Order α_s^2 results in
Bernreuther, Bonciani et
al., hep-ph/0604031



“... we conclude that the 2-parton QCD corrections to the lowest order asymmetry are moderate to small for $\sqrt{s} > 400$ GeV”

Scale variations yield <1% error @ NNLO

Top@LC: Theory input

EWK corrections to cross-section:

~3% at $\sqrt{s} = 500$ GeV

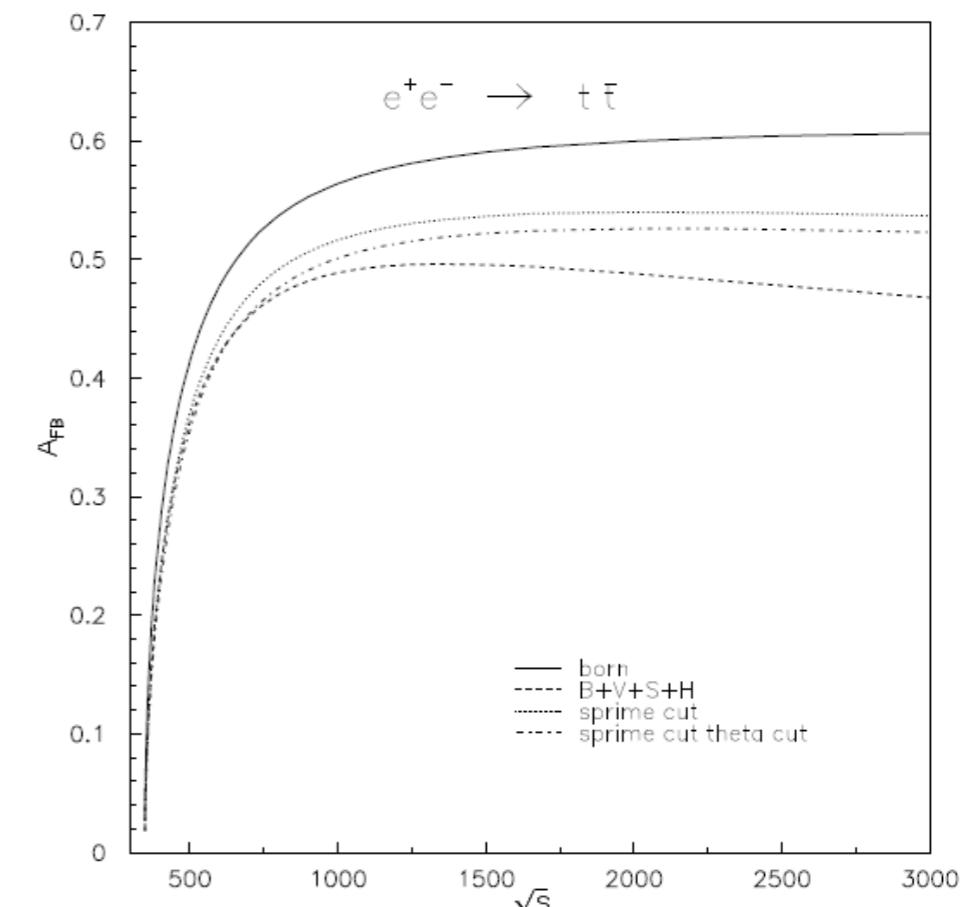
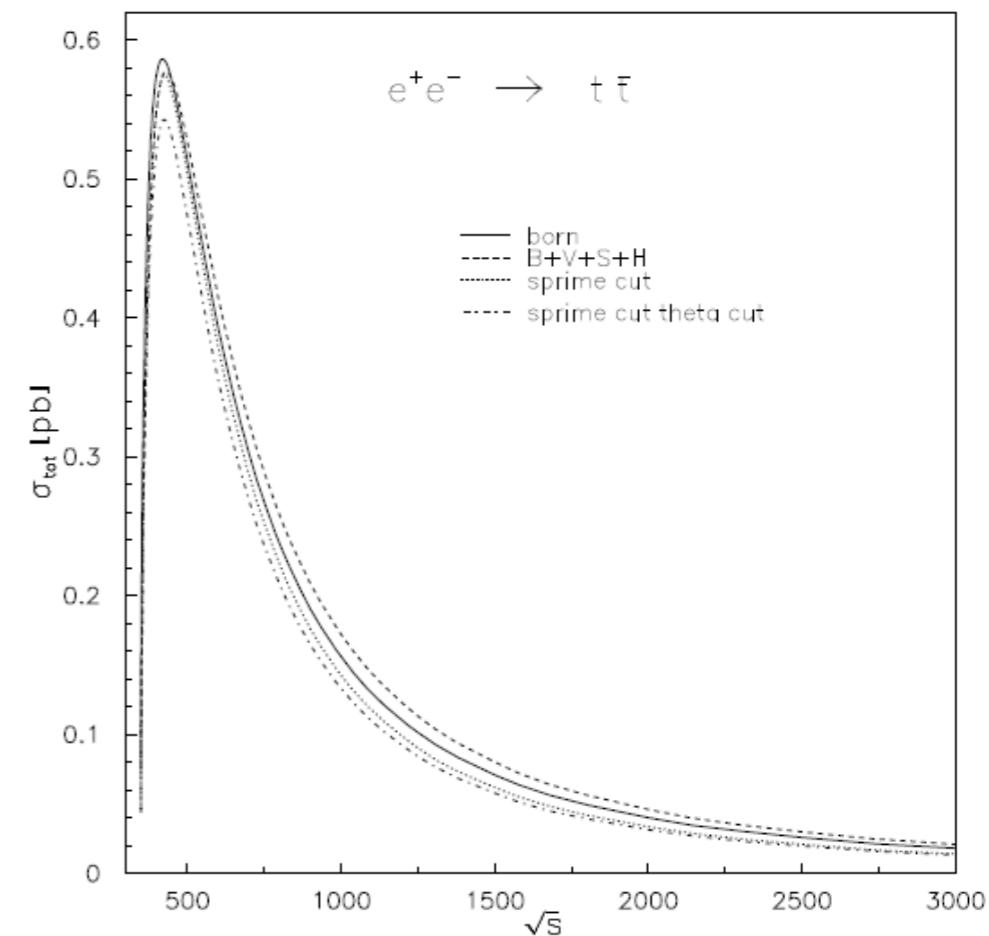
EWK correction to forward-backward asymmetry:
~20% at $\sqrt{s} = 500$ GeV

Electroweak corrections

Glover et al. hep/ph04010110

Fleischer et al. hep/ph0302259

EWK corrections from the decay
 $t\bar{t} \rightarrow bWbW \rightarrow$ six fermions
are expected to be order $\Gamma_t/m_t \sim 1\%$



Top@LC: Backgrounds

$\sigma(t\bar{t}) \approx 600 \text{ fb}$ at 500 GeV $L=500 \text{ fb}^{-1}$

$\rightarrow N_{\text{total}} \sim 570 \text{ K}$

Semileptonic $\sim 34\%$

Reducible backgrounds

$WW \rightarrow \text{no b quark}$

$bb \rightarrow \text{simple topology}$

Other top decays (τ)

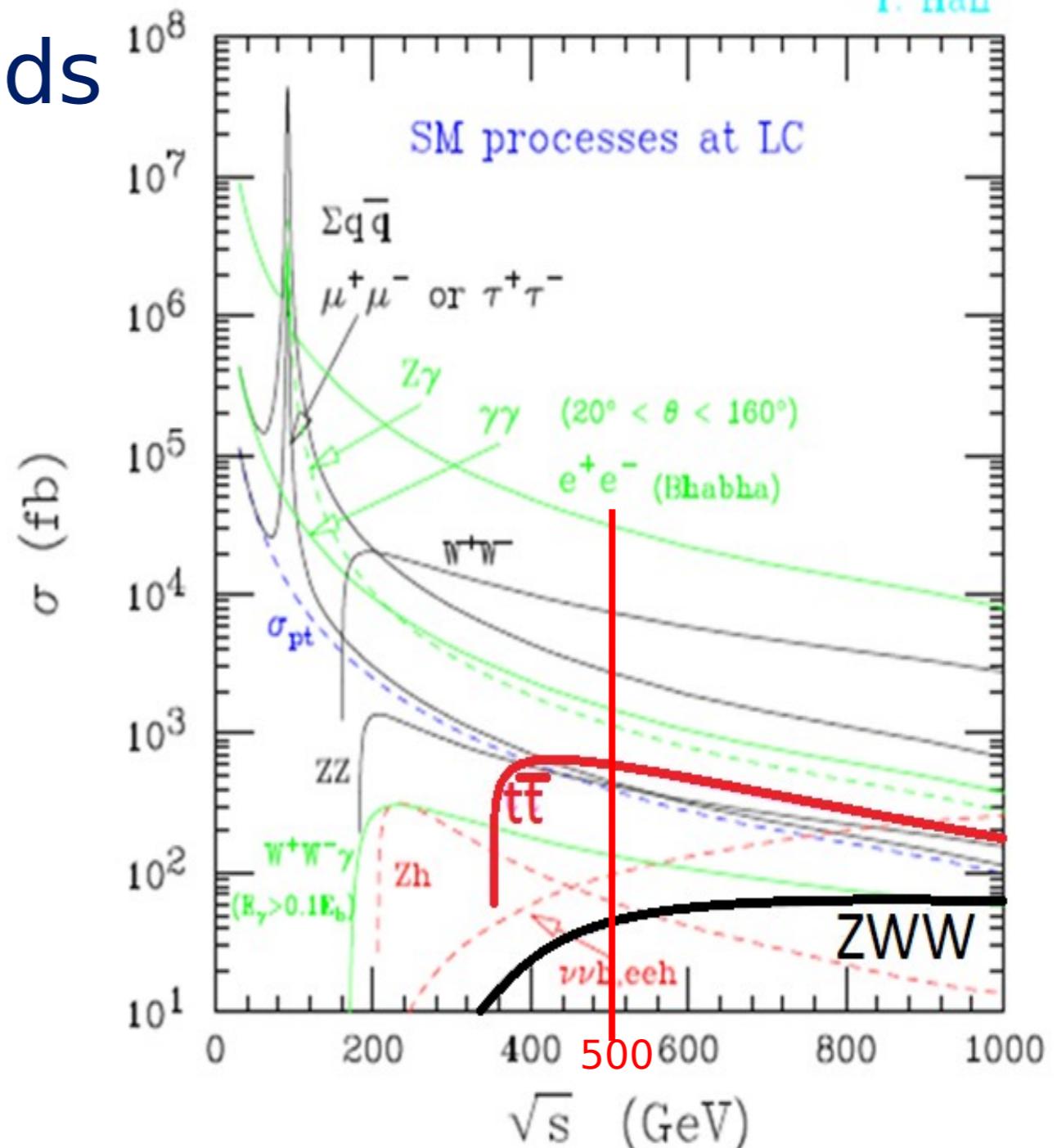
Irreducible:

Small but need to be subtracted

Other top decays (τ)

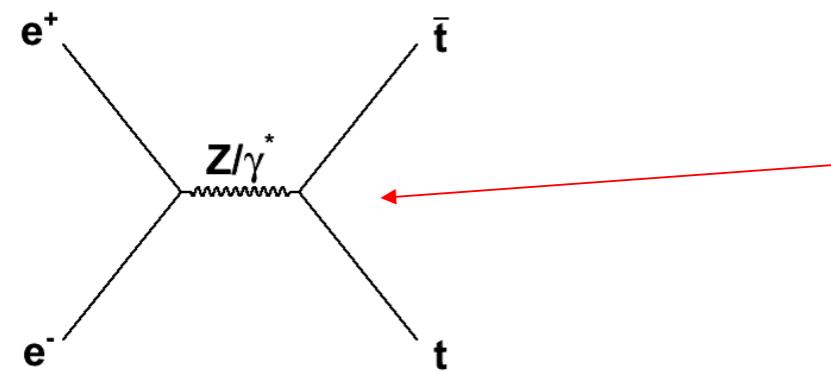
$ZWW (Z \rightarrow bb) \rightarrow 8 \text{ fb}$

Single top

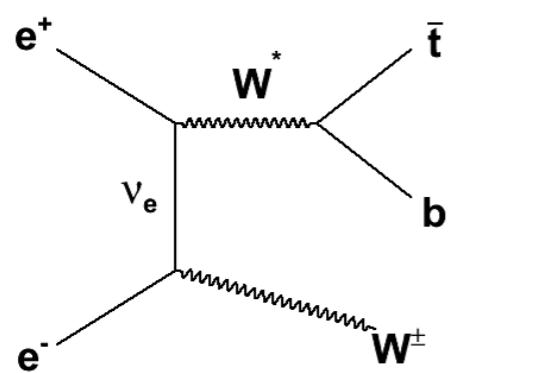


Process	tt	bb	WW	ZZ	ZWW
$A_{LR} (\%)$	36.7	62.9	98.8	31.0	89

Top quark couplings

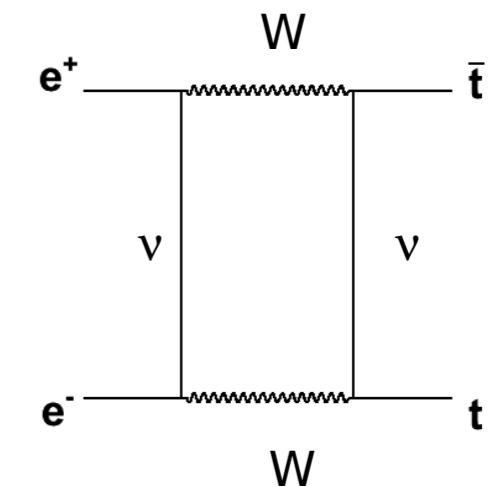
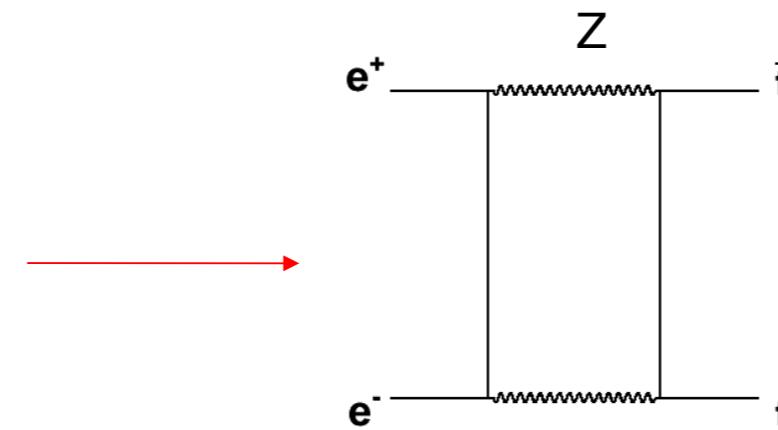


The vertex we are probing



Single top, reducible?

Higher-order contributions with different sensitivity to vertices (or even to different vertices)



So far: relate form factors to observables at tree-level. Higher-order corrections to be absorbed.

Top quark couplings

$$\Gamma_{t\bar{t}(\gamma,Z)}^{\mu} = ie \left[\gamma^{\mu} \left[F_{1V}^{\gamma,Z} + F_{1A}^{\gamma,Z} \gamma^5 \right] + \frac{(P_t - P_{\bar{t}})^{\mu}}{2m_t} \left[F_{2V}^{\gamma,Z} + F_{2A}^{\gamma,Z} \gamma^5 \right] \right]$$

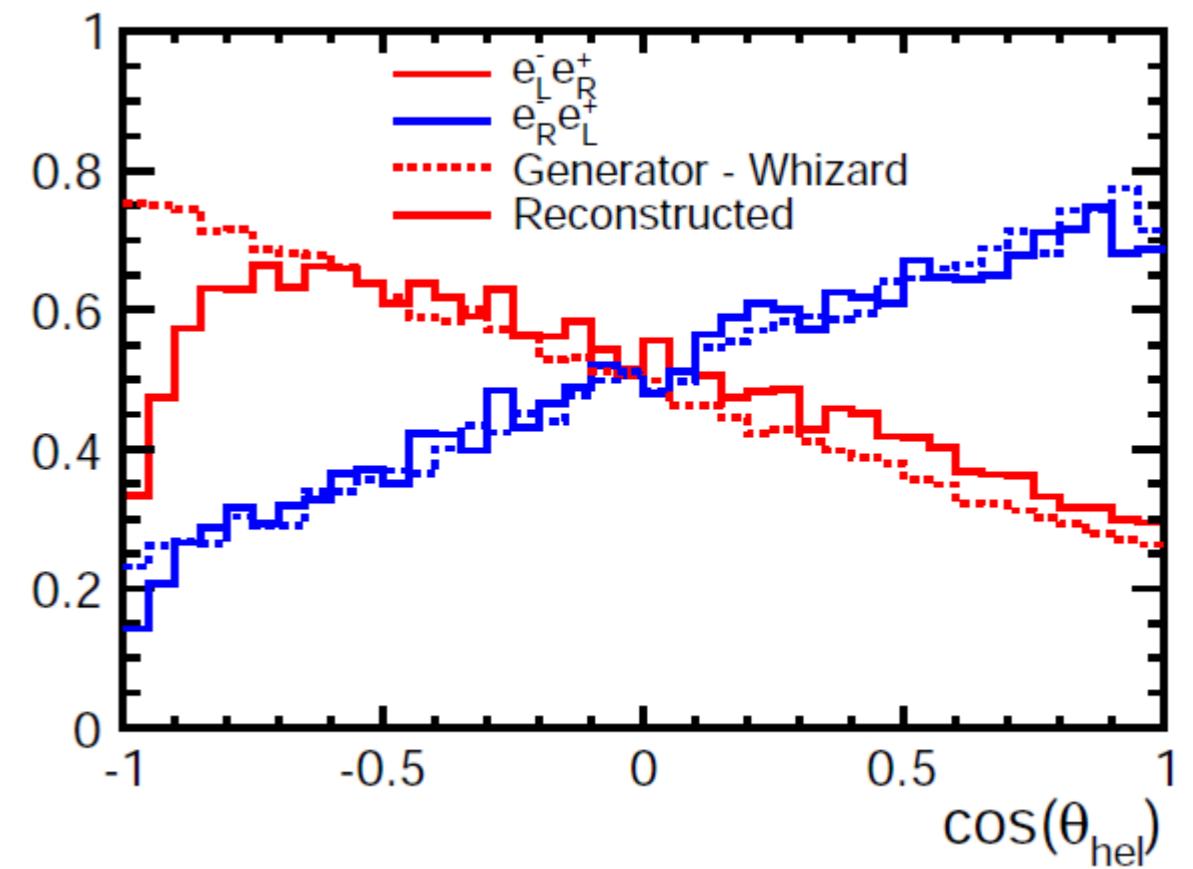
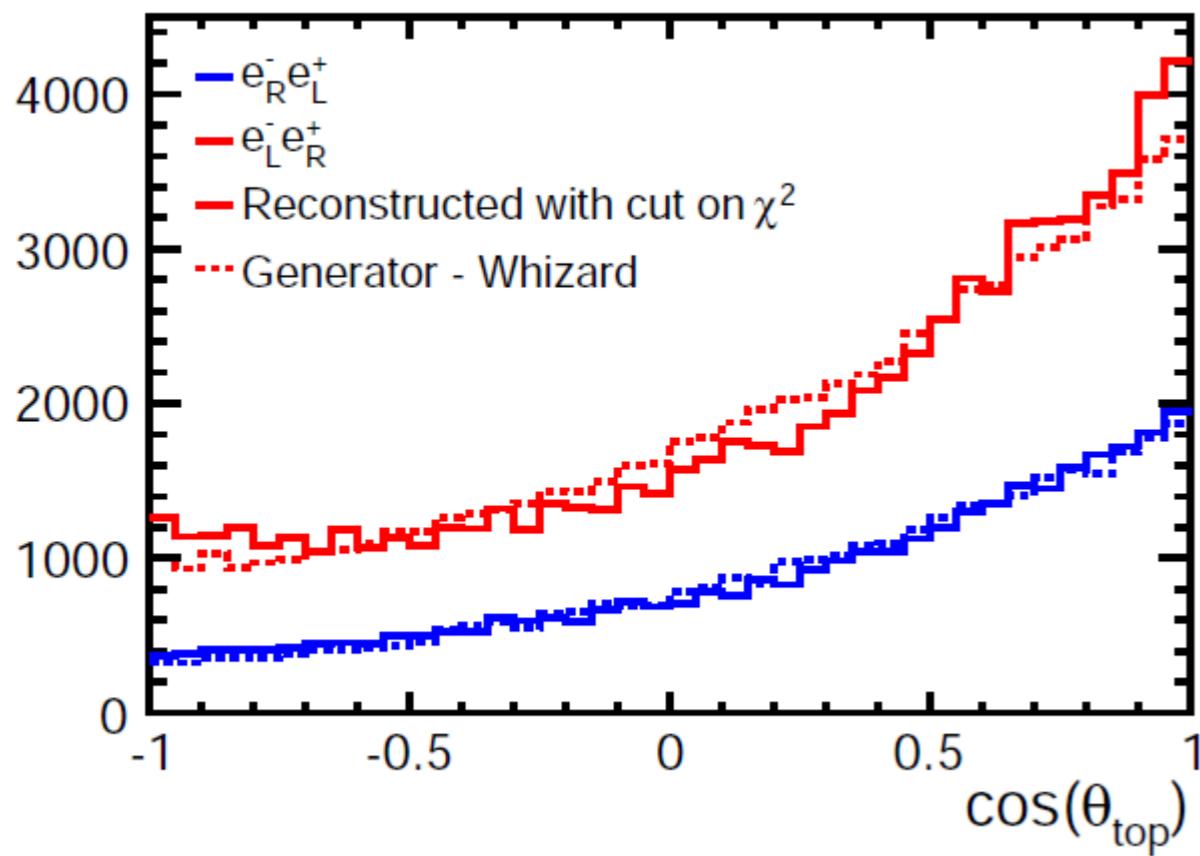
Parton-level studies show how measurements on $t\bar{t}$ production at LC (σ , A_{FB} , A_{LR} , ...) can constrain the form factors F

TESLA TDR claims sub-% constraints can be derived on some form Factors, and all can be measured to better than 4%.
To be explored in complete studies with detailed simulation

Control over beam polarization is vital!!

Experimental aspects

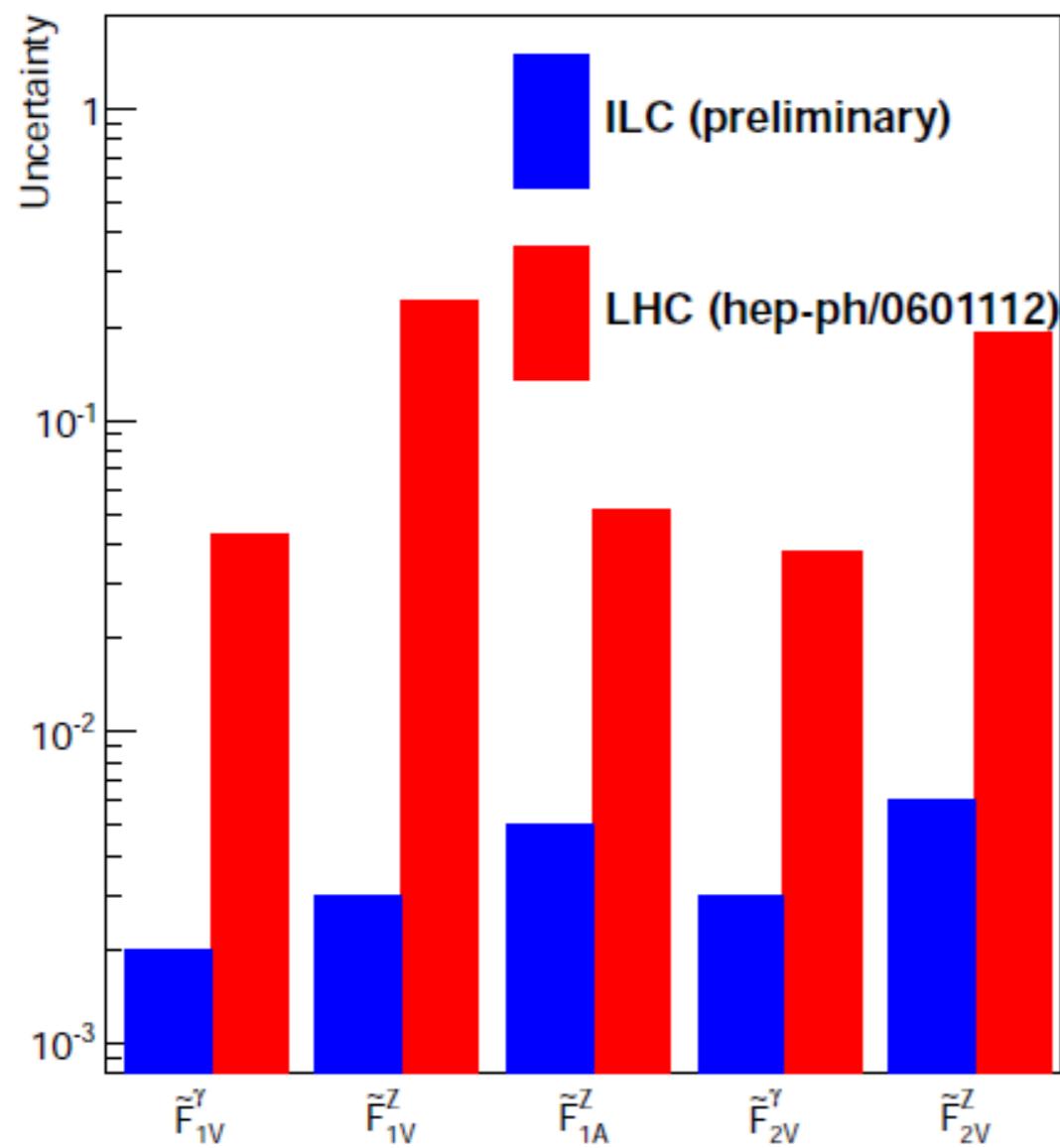
tt is not the simplest final state. Even at an LC, with fixed center-of-mass energy, top reconstruction is not straightforward.



Vertex of jet charge measurement known to work (even for a fully hadronic A_{FB} measurement)

Work in progress

Revisiting the parton-level study for the Detailed Baseline Design



Assumptions:

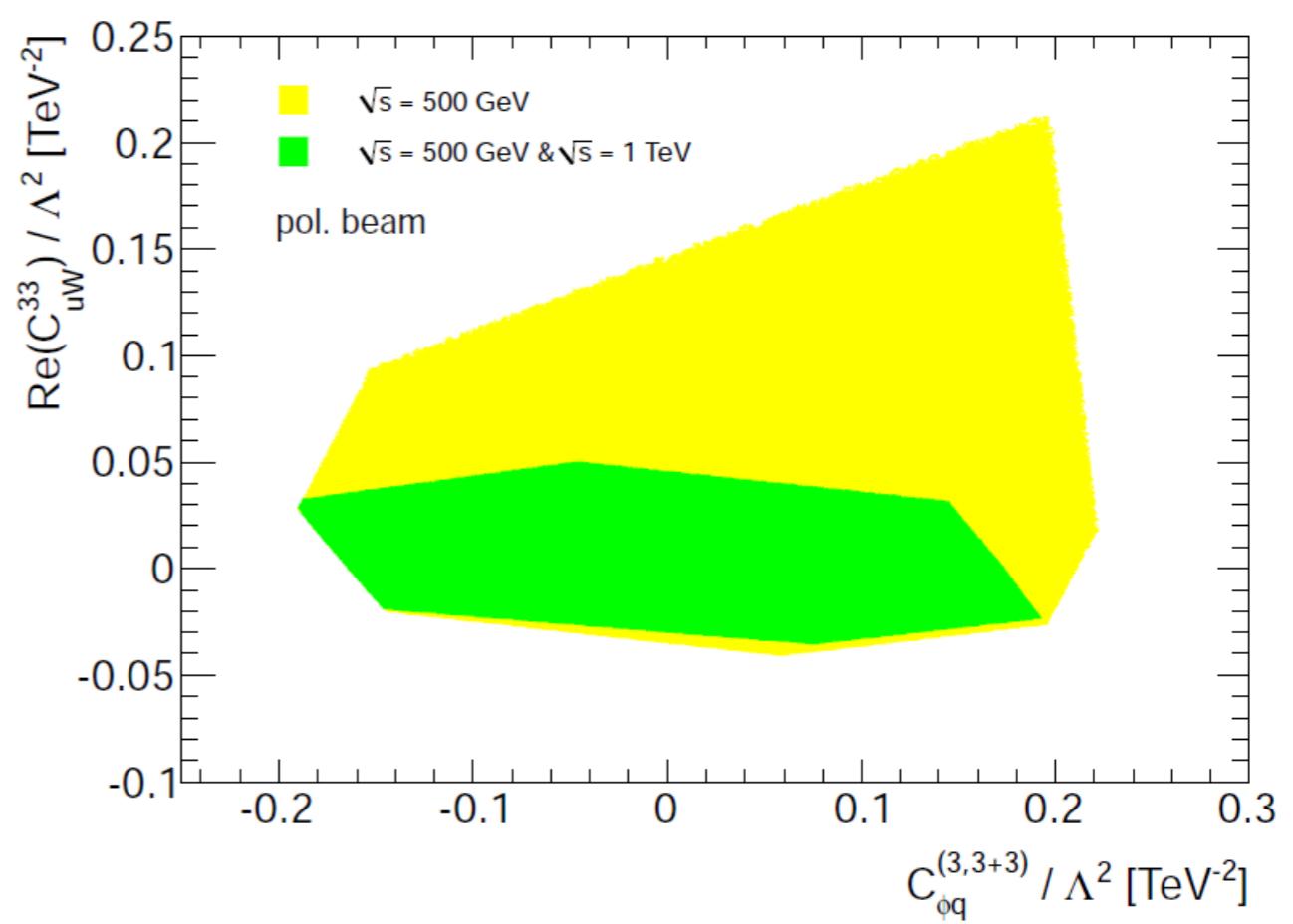
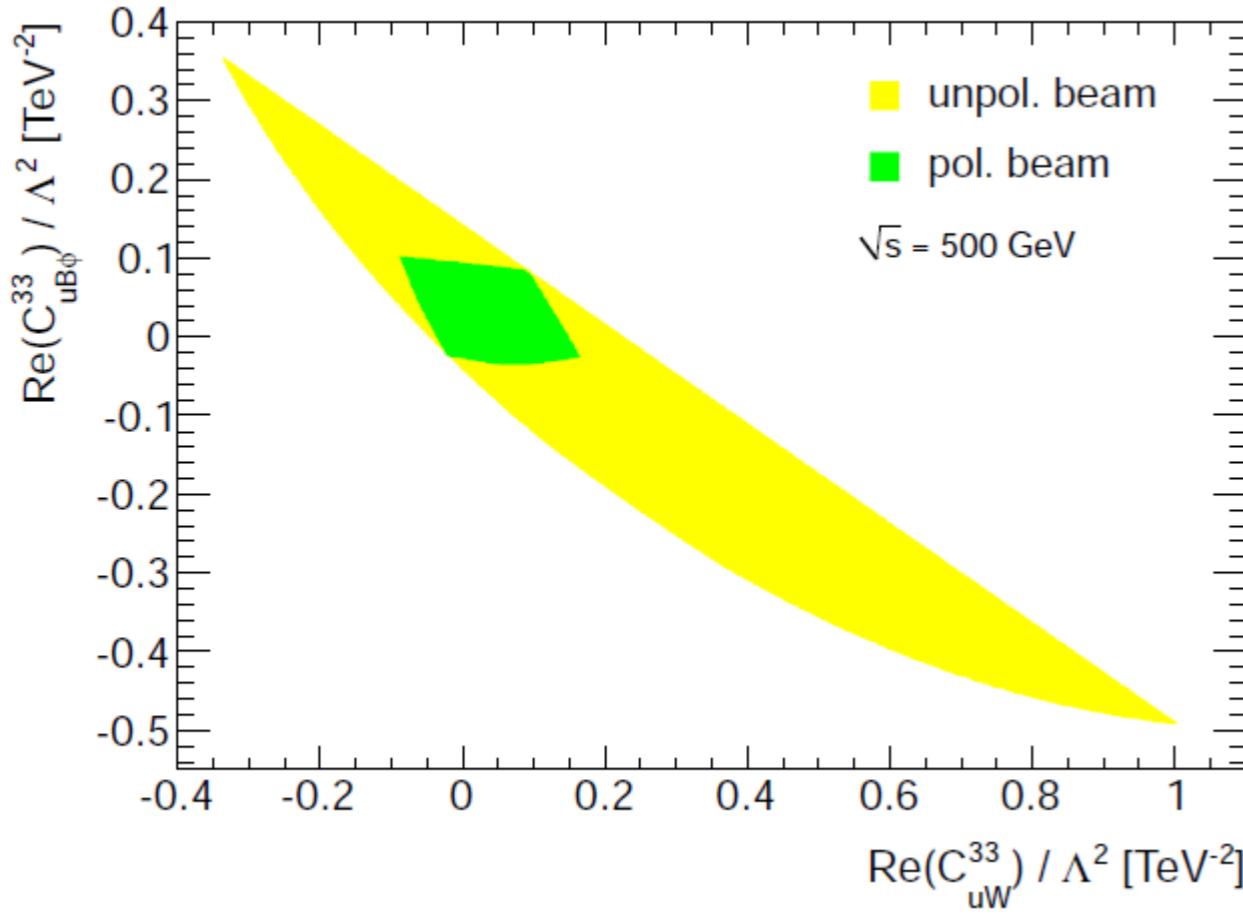
LC: $\sqrt{s} = 500$ GeV, $L = 500/\text{fb}$
 $P(e^-) = +/- 80\%$, $P(e^+) = -/+ 30\%$

LHC: 14 TeV, 300/fb

<http://www-flc.desy.de/lcnotes/>
→ LC-REP-2013-007

Full simulation in ILD concept to understand experimental challenges and estimate systematic errors. Preliminary: migrations due to ambiguities in tt reconstruction can be controlled at an LC

Effective operator interpretation



Constrain and disentangle all operators (anomalous couplings) using:

- polarization to distinguish photon and Z contributions
- center-of-mass energy to distinguish vector (γ^\perp) and tensor ($\sigma^{\mu\nu}$) terms

CAVEATS:

Simplified setup, only two operator strengths varied at any one time

Experimental uncertainties based on preliminary estimates

From: J.A. Aguilar et al., arXiv:1206.1033

Summary

LC top program offers precision tests of top quark couplings to γ and Z

$$\delta F_{1V}^{\gamma, Z}, \delta F_{1A}^{\gamma, Z} \sim 1\%$$

An order of magnitude better than LHC prospects!
Disentangling photon and Z!

All LC strong points conspire:

- calculability, theory errors at few per mil level
- controlled initial state, especially polarization
- excellent detectors to reduce exp. systematics

Tesla TDR promises similar performance for couplings not yet considered here

→ under investigation

Paper in progress, expect new results in ILC “white paper”